Internal Kinematics of Galaxies: 3D Spectroscopy on Russian 6m Telescope.

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Summary. We have considered some results concerning gas and stars kinematics of nearby galaxies recently obtained on the SAO RAS 6m telescope using the panoramic spectroscopy methods. The circumnuclear regions of the galaxies were observed with integral-field spectrograph MPFS. The large-scale ionized gas kinematics was studied with the scanning Fabry-Perot interferometer (FPI) in the multi-mode focal reducer SCORPIO. The main attention is given for kinematically decoupled regions in the galaxies: bars, spirals, polar disks and rings.

1 Introduction

The circumnuclear regions within the first kiloparsec in disk galaxies turn out to be decoupled on its dynamic characteristics. Using of the technique of panoramic spectroscopy makes it possible to study in detail the differences in kinematics of the stellar and gaseous components. I briefly review following types of kinematically decoupled regions in galactic disks:

– Non-circular motions caused by the dynamical effects (spirals, bars, colliding rings).
– Circular rotation in different planes or directions (polar rings, counter-rotating disks).
– Non-circular motions caused by a violent starformation (bubbles, high-velocity clouds).

2 Instrumentation

The study of two-dimensional kinematics of galaxies at 6m telescope of SAO RAS with the scanning FPI was started by our colleagues from Marseille Observatoire (J. Boulesteix et al.) in cooperation with team in SAO in the first half of 1980s. The observations were made with the system CIGALE. Then the IPCS was replaced by a CCD and in 2000 the first observations with a new multimode focal reducer SCORPIO [3] were carried out. Today FPI mode of SCORPIO provides $6' \times 6'$ field of view with a spectral resolution 1-2.5Å in the H_α, [NII], [SII] and [OIII] emission lines. So, using FPI data we

create monochromatic images as well as fields of the line-of-sight velocities in these lines (Fig. 1).

The integral field spectrograph MPFS based on the idea by Victor Afanasiev et al.: the combination of a lens array with a bundle of fibers [1]. First version of the spectrograph was developed in 1990. Current variant of the MPFS became operational at the 6 m telescope since 1998 [2]. Fibers transmit light from 16×16 square elements of the galaxy image to the slit of the spectrograph, together with 16 additional fibers that transmit the sky background taken away from the galaxy. The angular scale is $1''$ and the spectral resolution is $4-12$Å. Using MPFS for kinematics of galaxies allows us to build velocity fields of ionized gas as well as of their stellar component.

The descriptions of our spectrographs are available at SAO RAS web page: `http://www.sao.ru/hq/lsfvo/`

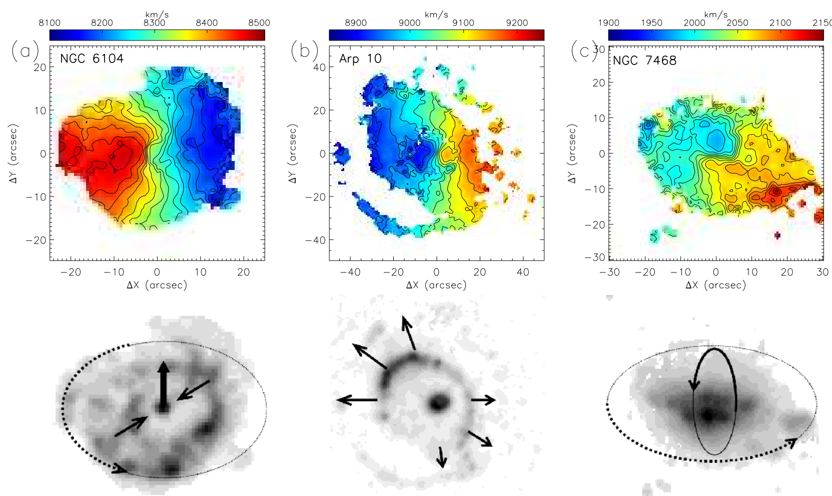

Fig. 1. FPI velocity fields of ionizing gas and H_α images with the sketch of gas motions: the radial inflow along a bar and the nuclear jet outflow in Sy NGC 6104 (a); the expansion of the emission ring in Arp 10 (b); polar disk in NGC 7468 (c)

3 The Examples of the Objects

3.1 Barred and Double-barred Galaxies

The values of non-circular motions in barred galaxies can be estimate in the detailed analysis of their velocity fields. For instance, Sy galaxy NGC 6104 where the ionized gas radial inflow motions along the bar co-exist with nuclear outflow caused by jet-clouds interactions, [11] (Fig. 1a).

Recently we have observed a sample of candidate double-barred galaxies and suggest that these objects are, in fact, galaxies with very different circumnuclear structure [7]. The majority of the observed morphological and kinematic features in the sample may be explained without the secondary bar hypothesis. Three cases of inner polar disks, one counter-rotating gaseous disk and seven nuclear disks nested in large-scale bars were found in this work.

3.2 Counter-rotation

The type of the motion of gas clouds may noticeably differ from the rotation of the stellar component even in 'quiet' galaxies without AGN. The characteristic case is a lenticular galaxy NGC 3945 (Fig. 2a). The velocity field of the stars in the circumnuclear disk shows the normal circular rotation. For the gas velocity field the situation is more complicated. In $r < 6''$ (0.5 kpc), the line-of-sight velocities of ionized gas are in the maximum amplitude to those of stars but opposite in sign. On larger distances the direction of rotation of gas changes abruptly and coincides with the stellar component rotation. The large-scale FPI velocity field confirms the fact of normal gas rotation at large radii, up to 11 kpc. Therefore, we have detected a circumnuclear disk of ionized gas rotating in the opposite direction with respect to the stellar component, [7]. This is probably attributable to a merger of an accreted gaseous cloud with the corresponding direction of an angular momentum [4].

3.3 Collisional Rings

Collisional ring galaxies represent a class of objects in which nearly circular density waves are driven into a disk as a result of an almost face-on collision with another galaxy. We have observed with FPI a pecular galaxy Arp 10, which has two rings (the inner and outer one), and extended outer arc. The H_α velocity field shows evidence for significant radial motions in both outer and inner galactic rings. We fit a model velocity field taking into account the regular rotation and projection effects. The expansion velocity of the NW part of the outer ring exceeds 100 km/s, whereas it attain only 30 km/s at the SE part [8]. Therefore, the asymmetric shape of the outer ring (fig. 1b) may be caused by a systematic difference in the ring expansion velocity and collisional origin of the rings is a proven fact.

3.4 Polar Rings and Nuclear Polar Disks.

Recently the team in St.Petersburg university (V. Hagen-Thorn, L. Shaliapina, V. Yakovleva) in a collaboration with us attempt to observe with FPI a gas kinematics in candidate polar-ring galaxies. The interesting results were already obtained. For example, they detected an inner gaseous disk whose rotation plane is almost perpendicular to the plane of the 'main' galactic

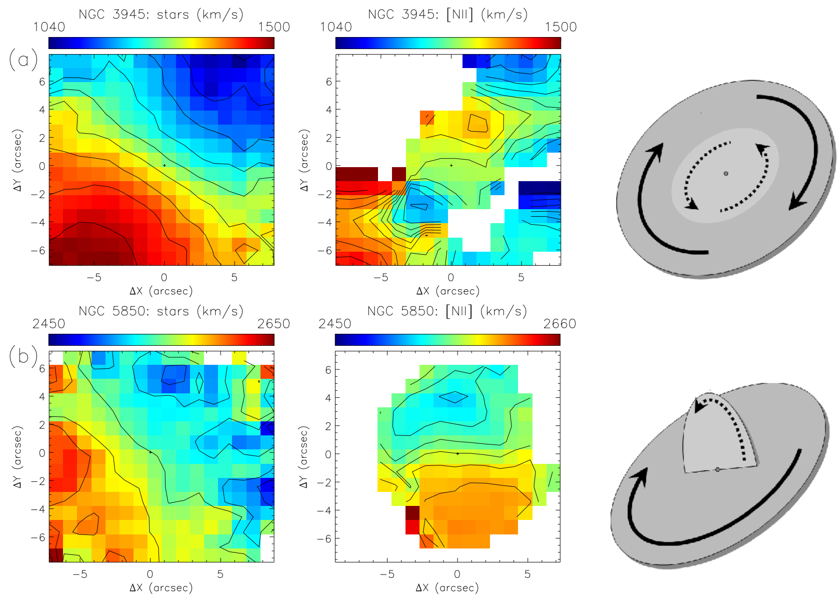

Fig. 2. MPFS data (from [7]): the velocity fields of stars and ionized gas for the circumnuclear region of NGC 3945 (a, counter-rotated disk) and NGC 5850 (b, inner polar disk). The right panels show the sketch of motions of gas and stars.

disk in NGC 7648 [9]. The Fig. 1c shows the sharp turn of isovelocities in the galactic circumnuclear region. The central collision of NGC 7468 with a gas-rich dwarf galaxy and their subsequent merging seem to be responsible for the formation of the disk.

In the barred galaxy NGC 5850 the direction of rotation measured from the stellar component coincides with the line of nodes of the disk whereas in the ionized gas it differs by more than 50° and coincides with the position angle of the central isophotes. Such a behavior is typical for a disk inclined to the galactic plane. A more reasonable assumption is that the gas, at $r < 1$ kpc, rotates in a polar plane with respect to the global galactic disk [7]. In this case, the polar gaseous disk lies orthogonal to the major axis of the bar. It is remarkable that similar polar mini-disks inside the large-scale bars or the three-axial bulge have already been detected in about twenty galaxies (see [10] and the contribution by Olga Sil'chenko in this volume).

3.5 Starformation in Dwarf Galaxies.

A burst of starformation also produces non-circular gas motions triggered by the combined effect of stellar winds and supernova explosions in rich stellar groupings. In dwarf galaxies the formation of giant multi-shell complexes around stellar groupings can proceed unhindered. See, for example, obser-

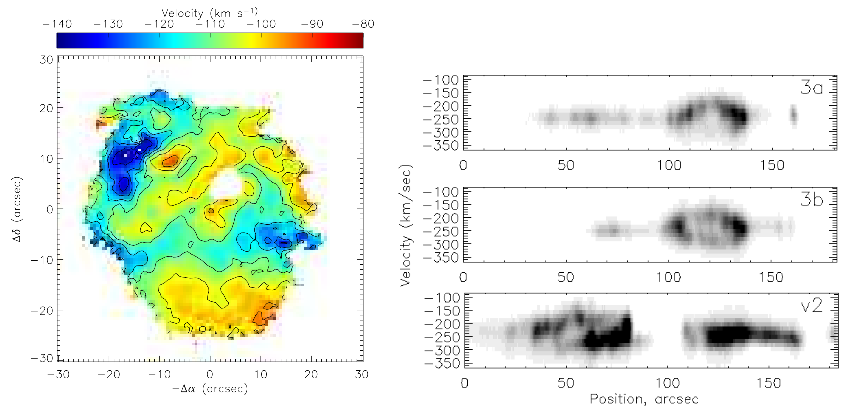

Fig. 3. Gas kinematics in dwarf galaxies: (left) – velocity field of VIIZw403 [6], (right) – the position velocity diagrams trough starforming regions in IC 1613. The remarkable velocity ellipsoids correspond to expansion of H_α envelopes.

vations with SCORPIO-FPI of the nearby irregular galaxy IC1613 [5]: the authors refined the expansion velocities of individual shells of the ionized and neutral gas (Fig. 3). In such galaxies the main part of line-of-sight velocities connects with an expansion of HII regions, frequently without any rotation (like VIIZw403, see also Fig. 3, left)

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